2004 GALVESTON BAY INVASIVE SPECIES RISK ASSESSMENT
INVASIVE SPECIES SUMMARY
Created by: Environmental Institute of Houston, University of Houston-Clear Lake
and the Houston Advanced Research Center

**Common Name: Purple loosestrife**

**Latin Name:** *Lythrum salicaria*

**Category:** Aquatic Plant

**Place of Origin:** Native to Europe

**Place of Introduction: Unknown** (First reported in the northeast coast of the U.S.) http://tncweeds.ucdavis.edu/esadocs/documnts/lythsal.html, http://www.wes.army.mil/el/pmis/plants/html/lythrum_.html (Accessed 19 March 2003).

**Date of Introduction: 1814** http://tncweeds.ucdavis.edu/esadocs/documnts/lythsal.html (Accessed 19 March 2003).

**States Effected:**

| | | | | | |
|---|---|---|---|---|---|
| Alabama | Illinois | Massachusetts | Nevada | Oklahoma | Utah |
| Arkansas | Indiana | Michigan | New Hampshire | Oregon | Vermont |
| California | Iowa | Minnesota | New Jersey | Pennsylvania | Virginia |
| Colorado | Kansas | Mississippi | New York | Rhode Island | Washington |
| Connecticut | Kentucky | Missouri | North Carolina | South Dakota | West Virginia |
| Delaware | Maine | Montana | North Dakota | Tennessee | Wisconsin |
| Idaho | Maryland | Nebraska | Ohio | Texas | Wyoming |

http://plants.usda.gov/cgi_bin/plant_profile.cgi?symbol=LYSA2 (Accessed 19 March 2003)

**Life History:** http://www.fs.fed.us/database/feis/plants/forb/lytsal/all.html (Accessed 19 March 2003)
"REGENERATION PROCESSES:
**Breeding system:** Purple loosestrife is a tristylous species (3 different style lengths), usually in a 1:1:1 ratio, indicating sexual reproduction is probably its most important means of regeneration [9]. It is primarily an outcrosser, as self-pollination in purple loosestrife is rare, and has been shown to reduce seed production [113].

**Pollination:** Purple loosestrife is insect pollinated. Most reports indicate honeybees are the main pollinators [44,74]. Others include bumblebees [73,74], leaf-cutter bees and carpenter bees [73], as well as a variety of butterflies [73,74]. Hummingbirds have been observed taking nectar from purple loosestrife in British Columbia [98], although pollination by hummingbirds is undocumented.

**Seed production:** Purple loosestrife produces an immense number of seeds. Estimates of seed production rates range from just over 100,000 seeds per plant for young plants with single stems [113], to over 2.5 million seeds per plant for established plants with an average of 30 stems per plant [129]. Although perennial, purple loosestrife is capable of producing viable seed during its 1st growing season [116]. Seed output is largely a function of plant age, size, and vigor [129]. Shoots growing in relatively dense stands tend to produce fewer and smaller inflorescences than those growing in more open areas [102].

**Seed dispersal:** Because seeds are small and light they are thought to be dispersed, at least in part, by wind [54,113]. However, Thompson and others [129] report observations that seedling densities decline sharply within a 33 foot (10 m) perimeter of the parent plant and seedlings are often distributed downslope from the parent plant rather than downwind, suggesting a limited role for wind dispersal. Dispersal via moving water is also likely [54,118,119]. Seeds and cotyledon stage seedlings are reportedly buoyant [9], although there are reports that purple loosestrife seeds don't float [119]. Floating seeds may disperse to suitable sites for establishment. Seeds that sink may germinate while submerged, then rise to the surface and drift to suitable sites for establishment [129]. Seeds may be transported in fur of mammals, plumage of waterfowl, mud attached to footgear, vehicle treads or cooling systems of outboard motors [54,128,129]. Thompson and others [129] also suggest birds may deposit ingested seeds in areas where wind or gravity-mediated dispersal seems unlikely.

**Seed banking:** Given its high seed output and ability to produce seed in its 1st growing season, purple loosestrife can establish substantial soil seed banks. Seeds may remain viable for at least 2 to 3 years [102,113], although the long-term viability of seeds stored in the soil seed bank remains under investigation [139]. Seeds may remain viable even when subjected to saturating conditions. Viability of seeds that were stored underwater was tested at 4-month intervals under ideal germination conditions. Germination declined from an initial rate of 99% to 93% after 1 year and 80% after 2 years [102].

Purple loosestrife has the potential to dominate the soil seed bank where it becomes well established. Soil samples taken from within purple loosestrife stands in emergent wetlands in southeastern Minnesota contained an average of 37,963 purple loosestrife seeds per $ft^2$ (410,000 /$m^2$) in the top 2 in (5 cm) of soil. Seeds were distributed within this entire profile and seed density increased with proximity to the soil surface. Under greenhouse conditions chosen to promote germination, and using soil samples from the above source spread 0.4 in (1 cm) deep, recruitment failed to exhaust the seed bank [138,140]. From the same experiment, purple loosestrife seedlings were found in 91% of untreated (no herbicide) 6.6 x 6.6 feet (2 x 2 m) quadrats, the most frequently encountered species in the soil seed bank [140].

**Germination:** Germination is greatest in unshaded, wet soils, with temperatures >68 degrees Fahrenheit (20º C) [20]. Shamsi and Whitehead [113] demonstrated germination is constrained at low temperatures between about 50 to 59 degrees Fahrenheit (10°-15° C), and no germination occurred below 57 degrees Fahrenheit (14° C). Experimental evidence indicates seed dormancy may be enforced by burial, with germination response decreasing linearly ($p = 0.001$, $r^2 = 0.89$) from 90% at the soil surface to 0% at 0.8 in (2 cm), even under conditions known to promote germination in wetland plants [138]. Any disturbance that redistributes seeds to within the upper 0.8 inch (2 cm) of soil is likely to promote germination. Although light exposure is a prerequisite for germination, length of exposure does not appear important [111]. Purple loosestrife seeds are capable of germinating underwater [65].

**Seedling establishment/growth:** Favorable recruitment conditions are largely a function of disturbance that creates areas where little to no vegetation is present [99]. Estimates of maximum initial seedling density vary greatly, from 926 to 1,852 $foot^{-2}$ (10,000-20,000 $m^{-2}$) on bare open mudflats [102] to 2.8 to 4.6 $foot^{-2}$ (30-50 $m^{-2}$) in vegetated semiflooded wetlands. In areas where large numbers of seeds are present in the seed bank, small changes in area favorable for establishment can yield large fluctuations in recruitment [1].

In order to begin successful establishment, floating seeds or propagules must settle on moist soil [129]. Purple loosestrife can establish in soil beneath standing water [65].

Growth is limited by cold temperature and is considerably slowed at around 46 to 50 degrees Fahrenheit (8-10º C) [141]. Light availability can also limit growth and development. Under diminishing light intensities, vegetative growth is slowed, the numbers of flowers, fruits, and seeds per fruit are fewer, and the average dry weight of fruits declines, but there is no change in average dry weight of individual seeds [111]. Growth is also affected by day length. Shamsi and Whitehead [111] found leaf area and plant dry weight were significantly ($P<0.05$) reduced when plants were subjected to a 9-hour photoperiod compared with a 16-hour photoperiod. Plants in the 9-hour treatment grew in a comparatively flattened, semi-prostrate condition.

**Asexual regeneration:** The rootstock is the main organ of perennation, and unaided wide vegetative spread is unlikely. New shoots arise from buds at the top of the rootstock [113]. Root crowns expand annually to accommodate increasing numbers of shoots, but may reach maximum growth at around 20 inches (0.5 m) in diameter [129].

Purple loosestrife can consistently resprout in response to aboveground damage, often fairly rapidly. A greenhouse experiment showed 91% of clipped seedlings resprouted within 42 days [40]. Live stems that are dislodged and buried can give rise to new shoots via adventitious buds [23,129]."

**Growth/Size:**

**2. "**Purple loosestrife is a non-native, perennial wetland herb [14,129]. Stems are erect, 1 to 8 feet (0.3-2.4 m) tall, becoming woody with age and persisting through winter and up to 2 years [9,14,74,118]. Mature, long-established plants are often 10 feet (3 m) tall and 5 feet (1.5 m) wide [129]. Plants may become increasingly bush-like by producing greater numbers of basal stems from the same rootstock each year [14,80,118,129]. Plants begin producing multiple stems from a single rootstock as early as the 2nd growing season [102]. Anderson [1] recorded single genets with over 130 stems produced from a single rootstock during a single season. He also estimated ages for individual plants up to 22 years. Observations have been recorded of particular rootstocks failing to generate shoots during a given year, but producing aboveground growth during each prior and subsequent season [129]."
http://www.fs.fed.us/database/feis/plants/forb/lytsal/all.html (Accessed 19 March 2003)

**Feeding Habits/Diet: NA**

**Habitat:**

**"**Moist soil to emergent shallow water areas, may even grow in moist upland areas"… "Seedlings established best on moist soil or mudflats" http://www.apms.org/plants/loosestrife.htm (Accessed 19 March 2003)

**"**Throughout its global distribution purple loosestrife is strongly linked with temperate climate and moist or saturated soils [129]. Unshaded, newly-exposed, moist soil appears most favorable for seedling establishment. Riverine habitats subjected to periodic but infrequent scouring, or lacustrine habitats subject to periodic water level reduction such as drought-exposed lakeshore or seasonal impoundment drawdown are good examples of habitats at risk of invasion. Once purple loosestrife seedlings become established, adults are quite flood tolerant [118]. Moisture is the most critical factor for growth and reproduction, but well-established plants can persist at dry sites for many years [21]. Keddy and Ellis [65] examined purple loosestrife seedling recruitment along a water level gradient, simulating conditions ranging from water levels 2 inches (5 cm) below the soil surface to standing water up to 4 inches (10 cm) above the soil surface. They found there was no significant ($p = 0.44$) effect of water depth on germination and early establishment of seedlings, indicating a broad tolerance for water level in the recruitment phase of purple loosestrife life history. Stream corridors with steep elevational gradients may be less susceptible to colonization by purple loosestrife due to gravitational constraints on seed dispersal [128].

Northern limits of purple loosestrife distribution may be strongly influenced by low growing season temperature. Under controlled conditions, growth was severely restricted at 46.4 degrees Fahrenheit (8 °C) compared with more "characteristic" growth at 64.4 degrees Fahrenheit (18°C) [112].

Purple loosestrife is found on both calcareous and acidic soils [112,113,129] and tolerates low-nutrient soils [113,117,141]. Typically found in open areas, purple loosestrife will tolerate some shade, but growth, reproduction and survival may be substantially reduced under shaded conditions [110,118].

Several characteristics of wetland or riparian habitats have been identified that may be predictive of invasibility by purple loosestrife. Assuming dispersal is largely via floating propagules, isolated wetland basins may be less susceptible to purple loosestrife colonization than areas with interconnected waterways. Additionally, narrow streams with steep gradients are probably less susceptible, because they are frequently scoured and contain fewer areas of slack water, while slower, broader flows are more likely to contain habitat suitable for colonization. Riparian areas that are mostly shaded are also less susceptible because purple loosestrife seedlings require relatively high light levels. Finally, the presence of one or more commonly associated taxa, such as cattails (*Typha* spp.), reed canarygrass (*Phalaris arundinacea*), sedges (*Carex*) spp., and rushes (*Juncus* spp.) may indicate a habitat that is highly susceptible to invasion by purple loosestrife [129]." http://www.fs.fed.us/database/feis/plants/forb/lytsal/all.html (Accessed 19 March 2003)

**Attitude (aggressive, etc.):**

**"**Major negative impact on wetlands in North America; reduces waterfowl food and nesting"
http://www.apms.org/plants/loosestrife.htm (Accessed 19 March 2003)

**"**Purple loosestrife displays many characteristics typical of pioneer species, such as rapid maturity, high seed production, tolerance of nutrient-poor environments, and high germination success. Yet North American populations, once established, also are potentially long-lived (22+ years), capable of growing to a relatively large size, and have shown the propensity for near-continuous, low-level recruitment in the absence of large-scale disturbance [1,129]. While evidence is somewhat limited, it is speculated natural mortality rates in adult plants are quite low [1].

Purple loosestrife, once established, can persist within a site for relatively long periods, even in the absence of frequent disturbance. After examining purple loosestrife population structure within several different communities in eastern Massachusetts, Anderson [1] concluded low levels of nearly-continuous recruitment are likely to occur in areas where mature plants (and the inevitable prodigious purple loosestrife seed bank) are present. Additionally, this trend is punctuated by occasional disturbances that provide conditions suitable for short-lived recruitment episodes in which relatively large cohorts of new plants are established.

But there is some question regarding the view that purple loosestrife inevitably dominates invaded sites in virtual monotypic stands. Anderson [2] points out that in a widely cited review by Thompson and others [129], estimates of the proportion of stand biomass attributed to purple loosestrife, which ostensibly increased over time following establishment, may instead have been attributable to increases in the number of stems per genet rather than greater numbers of individual plants. The number of annually produced stems per single genetically distinct plant has been shown to be a good predictor of the age of that individual [1]. Anderson [2] also notes observations described in Thompson and others [129] were strictly visual assessments, and since no hard data was collected, there is no way to definitively ascertain what, if any, changes in biomass distribution among species may have occurred."
http://www.fs.fed.us/database/feis/plants/forb/lytsal/all.html (Accessed 19 March 2003)

**"**This species has been nominated as among 100 of the "World's Worst" invaders"
http://www.issg.org/database/species/ecology.asp?si=93&fr=1&sts= (Accessed 19 March 2003)

"Often populations have spread so aggressively that native vegetation is excluded. Several garden races, some with larger rose-red petals, have been produced from this species and are cultivated. It is estimated that 200,000 ha of wetlands in the U.S. are lost annually through invasions of this species." http://www.wes.army.mil/el/pmis/plants/html/lythrum_.html (Accessed 19 March 2003)

**Physical Description:**

"Erect herbaceous perennial, overwinters by root crown, showy purple flowers, prolific seed production"
http://www.apms.org/plants/loosestrife.htm (Accessed 19 March 2003)

"Purple loosestrife is found across a variety of freshwater wetland habitats in North America, and consequently is associated with a variety of plant taxa, functional guilds and communities. Habitats where it is likely to be found include: freshwater marshes

[27,94,102,105,127,129], streambanks or lakeshores [130], floodplains [81,102,129], seasonally-wet meadows/wet prairies [8,10,129], bogs [127], vernal ponds [59], openings in forested swamps [64], intermittent streams [105], shallow impoundments, and ditches and canals [102,105]. Purple loosestrife is listed by the U.S. Fish and Wildlife Service Office of Biological Services as a typical broadleaf plant of Palustrine Persistent Emergent Wetlands [30]. http://www.fs.fed.us/database/feis/plants/forb/lytsal/all.html (Accessed 19 March 2003)

"Leaves are 2 to 6 inches (5-14 cm) long and attached close to the stem [14]. Flower spikes vary in length from > 40 inches (1 m) to only a few inches, and only 2 to 3 inches (5.1-7.6 cm) of the spike typically display open flowers at any given time [9,74]. Fruits are capsules 2-3 mm in length [57]. Seeds measure approximately 400 x 200 microns, and weigh approximately 1.8 x $10^{-6}$ ounces (50 µg) per seed, which is comparatively quite small among North American temperate wetland plants [116,129]. Seedlings quickly develop a thick, hardened taproot [113]. Mature plants subjected to persistent flooding respond by forming aerenchymous (containing large intercellular air spaces) tissue, permitting oxygen flow to submerged roots [118]. The preceding description provides characteristics of purple loosestrife that may be relevant to fire ecology and is not meant to be used for identification. Keys for identifying purple loosestrife are available in various floras (e.g. [58,72]). Photos and descriptions of purple loosestrife are also available online from The Nature Conservancy's Wildlands Invasive Species Team and Minnesota Sea Grant. Check with the native plant society or cooperative extension service in your state for more information." http://www.fs.fed.us/database/feis/plants/forb/lytsal/all.html (Accessed 19 March 2003)

**Management Recommendations / Control Strategies:** include references for existing site-specific strategies

**"**IMPACTS AND CONTROL:

**Impacts:** Purple loosestrife can be highly competitive, often reported as occurring in dense, monospecific stands, with the potential to dominate wetland plant communities where it occurs (see Successional Status in the BOTANICAL AND ECOLOGICAL CHARACTERISTICS section) [1,42,66,67,79,129,136,137]. While it is evident that invading purple loosestrife may have harmful impacts on native flora and fauna, more research is needed to clarify the extent of these impacts. Hager and McCoy [48] and Anderson [2] provide critical reviews of literature describing purported negative impacts caused by purple loosestrife in North America. Both papers express concern that widespread claims of ecological harm caused by purple loosestrife are largely unproven. In a widely cited review of purple loosestrife literature in North America, Thompson and others [129] describe encroachment of purple loosestrife around the margins of a waterfowl impoundment in central New York. Their estimates of percent of total plant biomass contributed by purple loosestrife along dike areas of the impoundments describe "dramatic" increases over about a 15-year period. Based on visual estimates of plant biomass, the authors contend that native plant species were displaced, vegetation structure was altered, and habitat quality for nesting waterfowl was seriously degraded. The paper by Thompson and others [129] demonstrates how untested hypotheses can be perpetuated in the literature until they become widely accepted, without the benefit of experimental analysis [48]. As emphasized by Anderson [2], "detailed, quantitative data are needed to understand loosestrife's natural history, population dynamics, and impacts on native ecosystems if we are to effectively manage this plant."

Because purple loosestrife has demonstrated strong competitive abilities where it has invaded North American wetland communities, there is concern that it may diminish native plant diversity. For instance, competition with purple loosestrife has been suggested as a contributing factor in the decline of the rare Long's bulrush (*Scirpus longii*) in Massachusetts [28]. However, studies published to date have failed to demonstrate a deleterious effect of purple loosestrife on native plant diversity. Treberg and Husband [130] examined the association between purple loosestrife abundance and vascular plant richness along the Bar River in Ontario. Purple loosestrife had been present in this area for at least 12 years and there was a wide range in established plant densities. They found no significant ($P<0.05$) difference in mean species richness associated with the presence or percent cover of purple loosestrife, and no plant species was significantly ($P<0.05$) more likely to be found in the absence of purple loosestrife than in its presence. Anderson [1] showed no significant ($P<0.05$) correlation between total species richness and either percent cover, genet density or median age of purple loosestrife, even in plots containing 18-20 year old purple loosestrife plants. He suggested areas with apparent purple loosestrife monocultures perhaps had low species richness to begin with, and species richness more likely resulted from habitat heterogeneity rather than the presence of innately competitive species. More research is needed in this area.

Purple loosestrife colonization has been purported to have detrimental effects on birds, based on: a) creation of unsuitable nesting habitat and b) low food potential of purple loosestrife relative to vegetation it displaces. However, published studies and observations indicate impacts on birds are not yet clear. Marsh wrens prefer cattails to purple loosestrife for nesting [101,142]. There is speculation that invasion of riparian areas in Nebraska may have adverse effects on important night-roosting habitat for migratory sandhill cranes. Purple loosestrife invasion is predicted to have detrimental effects on nesting habitat of black terns and canvasbacks in the north-central United States, but this has not been tested [129]. Whitt et al. [142] found purple loosestrife-dominated habitats had significantly ($P=0.003$) higher bird densities but significantly ($P=0.03$) fewer bird species than other habitats. These higher densities were mainly due to increases in populations of a single species, the swamp sparrow.

Purple loosestrife colonization can substantially reduce or eliminate open water in small marsh areas, potentially reducing its usefulness for waterfowl. In areas with substantial seed banks, mudflats that are commonly used as feeding areas by shorebirds are impacted by rapid, dense colonization by purple loosestrife seedlings. Decline in the extent of open water habitats from increased emergent purple loosestrife can retard access to aquatic prey items such as fish and aquatic invertebrates. Important aquatic food plants for wildlife such as pondweeds (*Potamogeton* spp.) are inhibited under the shade of emergent purple loosestrife [102]. Invading purple loosestrife in coastal British Columbia's Fraser River estuary may have negative effects on detrital food chains [45].

Thompson and others [129] have illustrated how muskrats might interact with purple loosestrife in a manner detrimental to muskrats. Muskrats apparently find stems of purple loosestrife much less palatable then those of cattail, but they do cut purple loosestrife stems. As they forage they favor cattail stems, potentially shifting the competitive balance toward the less palatable purple loosestrife. The ability of muskrats to shift the competitive balance between cattails and purple loosestrife was corroborated by Rawinski [102] from observations of mixed stands where muskrats were present. At a particular site, muskrats removed entire patches of cattail, leaving purple loosestrife the only remaining emergent. Muskrats may further favor purple loosestrife seedling establishment following den construction. This activity can cause substantial soil disturbance that is rapidly colonized by purple loosestrife seedlings during lower summer water levels. Because of their ability to generate new vegetative growth, partially eaten purple loosestrife stems also represent potential new propagules, adding to its competitive advantage [23]. As community composition shifts from cattails to purple loosestrife dominance, habitat quality and subsequent muskrat carrying capacity apparently decline [129].

Conversion of wetland pasture to predominantly purple loosestrife is believed to reduce forage value for livestock and deer [128]. As purple loosestrife density increases and mature plants produce greater numbers of shoots, the woody nature of purple loosestrife stems diminishes forage value [118].

Purple loosestrife may have adverse effects on habitat of the threatened bog turtle, although details are scant [26,68].

Purple loosestrife invasion may be detrimental to production of natural and domestic wild rice in areas of the upper Midwest, particularly in commercial wild rice paddy operations where water level manipulation presents ideal germination conditions. Dense purple loosestrife infestations can also undermine the functionality of drainage waterways, such as irrigation ditches [118].

Water level manipulations in impoundments have been hindered by threat of purple loosestrife invasion. A 1000-fold increase in acreage containing purple loosestrife was noted over a 23-year period in a central New York wetland and the cause was speculated to be recurrent drawdown of impoundments [102]. In areas managed for waterfowl production, such as many federal and state wildlife refuges, water level draw-downs in impoundments may provide establishment opportunities for purple loosestrife. Drawdowns are often executed to encourage recruitment of plants valuable to waterfowl such as cattails, smartweed (*Polygonum* spp.) and wild millet (*Echinochloa* spp.) on exposed soils [91].

Invading purple loosestrife is being monitored in the middle Snake River corridor in Idaho for effects on stream channel dynamics. Purple loosestrife is colonizing gravel bars under low flow conditions. Once established, it appears able to withstand inundation and flowing water conditions better than native annuals. It is feared that persistent purple loosestrife plants may contribute substantially to sediment trapping, leading to gravel bar aggradation, closure of small channels, and despoiling of secure, predator-free island nesting habitat for local waterfowl [33].

**Control:** Land managers concerned about invasive purple loosestrife should focus on eliminating small, recently-established populations before tackling large, well-established populations. Buildup and persistence of purple loosestrife seed in the soil seed bank appears to be the most problematic, long-term obstacle in eradicating, or at least controlling purple loosestrife. Preventing seed production and seed bank accumulation within recently-established stands is a pragmatic goal, especially in the face of limited resources and knowledge [138,139]. Welling and Becker [138] demonstrated the potential difficulty managers face with attempts to exhaust seed banks in areas where purple loosestrife is well established, although not necessarily monodominant. Because seed dormancy is enforced by burial at relatively shallow (>0.8 inch (2 cm)) depth, and because purple loosestrife seed banks may contain thousands of seeds per square foot at these depths, even successful eradication of extant adult plants and new recruits from near-surface germinants may not suffice for successful long-term control. Even the ability to exhaust near-surface (<0.4 inch (1 cm)) seed banks by promoting germination and removing emergent seedlings is in question.

Any disturbance or management activity that fragments live stem or root tissue is likely to result in the spread, rather than containment of purple loosestrife [23,118]. Live stems that are dislodged and buried can give rise to new shoots via adventitious buds [23,129]. Carp may play an important role where they co-occur with purple loosestrife. Carp eat the roots of purple loosestrife, sometimes until the plants are dislodged and float away. These plants then become potential propagules if they lodge on suitable substrate [102].

Detection and control efforts may be hindered by purple loosestrife's propensity to occasionally remain dormant for an entire growing season. Some plants fail to generate aboveground shoots during a particular year, but exhibit normal growth from the same rootstock in preceding and following years [43,129].

Prevention: It is important to avoid management activities that may enhance the risk of purple loosestrife invasion and expansion. Examples of mitigative efforts are a) encourage establishment, growth, or perpetuation of native woody cover that might provide enough shade to depress or discourage purple loosestrife, b) minimize water level fluctuations in manipulated wetlands or waterways that might encourage establishment of purple loosestrife seedlings, especially early-season draw-downs that expose bare substrate, and c) avoid any form of stress or disturbance to extant native plant communities in susceptible areas, such as disturbing soil with heavy machinery, and where such activities are unavoidable, monitoring impacted areas to detect invaders [129].

Periodic, systematic monitoring of susceptible habitats is strongly encouraged [144]. Development of local populations, as expressed by percent biomass constituted by purple loosestrife, is roughly a logistic function through time. Initial rate of spread of local infestations is slowed when extant competition is strong. As a result, early detection and eradication of colonizing plants is highly preferred. Fortunately, early detection is aided by the tall, showy flower stalks and lengthy period of bloom. Once purple loosestrife becomes strongly established, with many (>10) flowering stems per rootstock, multiple clumps forming monospecific patches or stands, and establishment of a seed bank, eradication becomes more expensive, intrusive, and difficult [129].

Spread of purple loosestrife in natural areas likely has been accelerated by the development, sale and use of various loosestrife cultivars for horticultural purposes. Sale and utilization of ornamental loosestrife cultivars should be curtailed to prevent the risk of further dissemination into previously uncolonized areas. Cultivars are capable of contributing viable seed and pollen to wild populations, and claims of sterile hybrids have been shown to be mainly false [3,75,93].

As with most invasive species, public education plays an important role in preventing establishment and spread of purple loosestrife. Planting of loosestrife cultivars for horticultural purposes should be strongly discouraged. Individuals who frequent areas susceptible to invasion can aid in prevention by washing boots, clothing, equipment, etc. before exiting such areas, and should be encouraged to identify and report potential new infestations to authorities.

Integrated management: A single method may not be effective for long-term control or removal of purple loosestrife. Integrated management involves using several management techniques in a well-planned, coordinated and organized program. Many combinations of control methods can achieve desired objectives. Methods selected for a specific site will be determined by land-use objectives, desired plant community, extent and nature of infestation, environmental factors (nontarget vegetation, habitat types, climate, hydrology, etc.), economics, and effectiveness and limitations of available control techniques [103,114].

Cultural: Seeding of competitive vegetation in areas where bare soil has been exposed may be a useful mitigative measure. This may be especially helpful where presence of seed in the soil seed bank indicates potential for robust purple loosestrife regeneration. Experiments examining the effectiveness of seeding Japanese millet (*Echinochloa esculenta*) to reduce the impact of purple loosestrife recruitment have shown mixed results [81,140]. In addition to providing competition against purple loosestrife seedlings, Japanese millet may be used by waterfowl and is thought to represent a minimal threat of invasiveness, although it is not native to North America [129]. Seeding native species may provide a desirable postdisturbance community, but explicit tests of the competitive abilities of various native plants when seeded with purple loosestrife are lacking. Seeding of competitors should take place immediately following exposure of soil to maximize their competitive abilities [81].

Flooding infested areas by raising water levels for extended periods may eliminate purple loosestrife from impoundment sites [47]. Flooding duration is more likely to influence mortality than depth of flooding, but specific guidelines are lacking [9]. Persistent high water conditions can slow the growth and reproductive capacity of purple loosestrife and over several years may eliminate extant stands, but results are variable and interactions with other factors poorly understood [81]. In plots subjected to consistently high water levels (16 inch (40 cm) mean depth)), competition with narrow-leaved cattail significantly ($P<0.001$) reduced stem densities of purple loosestrife compared with flooded stands where purple loosestrife was the predominant species [101]. More research is needed to determine optimal flooding duration and factors that influence variability in the effect of flooding duration [9].

Effectiveness of flooding as a control measure may be enhanced by cutting purple loosestrife stems prior to raising water levels [81]. Cut material should always be removed from the site to prevent spread of vegetative propagules. The efficacy of flooding may be influenced by the presence of carp within contiguous waterways, although the ultimate effects are unclear. Carp may reduce purple loosestrife by grazing its roots or enhance its spread by disseminating vegetative propagules [102]. Carp are not native to North America and should not be introduced as a means to control purple loosestrife.

Consistent spring and early-summer flooding may inhibit purple loosestrife seedling establishment [9,137]. Flooding seedlings 0.8 to 4 inches (2-10 cm) tall for 9 weeks at depths up to 12 inches (30 cm) did not significantly ($P<0.05$) reduce mean stem densities. Most plants continued to grow, if slowly, while submerged, and plants which emerged above the surface quickly resumed rapid growth [53]. Established purple loosestrife plants can survive in deepwater emergent habitat, in part by development of aerenchymous (containing large intercellular air spaces) stem tissue that facilitates gas exchange in aquatic environments.

Several factors may hinder the effectiveness of controlling purple loosestrife by flooding. Managers may be constrained in their ability to manipulate water levels by the geologic profile of the site or by development along its margins. Substantial warm season evaporation can contribute to this problem. Sustained high water levels may be detrimental to desirable native emergent or shoreline vegetation. Once purple loosestrife has been killed, managers should consider species composition within the remnant seed bank, and the ensuing colonizing community, when water levels have been reduced. It is likely that purple loosestrife seedlings will recolonize the newly exposed soil and further management may be inevitable.

Physical/mechanical: Cutting stems or removing flower heads prior to seed dissemination can prevent local seed bank accumulation. Late-summer cutting appears to reduce vegetative growth more effectively than mid-summer treatments. However, cutting stems is unlikely to prevent perennial stem growth [47,102]. Cutting flower heads may be useful in preventing further seed production when primary control activities, such as herbicide application, require more than 1 season to completely eradicate purple loosestrife [13]. Cutting purple loosestrife stems underwater at various times in summer was ineffective [52].

Digging or hand-pulling plants are recommended for early infestations or a few scattered plants. Digging or pulling young plants in recently colonized areas can be effective in preventing establishment of dense, intractable stands and buildup of substantial seed banks. Early detection is important since established plants may rapidly become too large and deep-rooted for easy removal [102,129]. Because growing points of the plant are located on the root crown, removal of as much rootstock as possible is strongly encouraged [23,47]. Pulling entire plants is easiest when the soil is wet [102,131]. All pulled plant material should be removed from the site to prevent vegetative reproduction from discarded fragments [23]. Spot spraying individual plants with herbicide may be less time and labor intensive when infestations become too large for removal by pulling or digging [129].

Fire: See "Fire Management Considerations" in the FIRE EFFECTS section of this summary.

Biological: The objective of biological control is to re-establish ecological relationships that have evolved between purple loosestrife and its native predators in order to suppress invasive populations and reduce harmful impacts. Potential advantages of biological control are cost effectiveness at large scales, sustainability, and benign effects in the nontarget environment [22,131]. The Nature Conservancy's Weed Control Methods Handbook provides a comprehensive discussion of considerations and safety issues in developing and implementing a biological control program.

Plant communities where purple loosestrife is found are similar in North America and Europe. Because native insect herbivory inhibits purple loosestrife performance in Europe, it is hoped introductions of European insect herbivores may work to reduce the competitiveness of purple loosestrife in North America, while releasing native plants from suppression [18,19].

The following table lists non-native insects released in North America to control purple loosestrife:

| Control Agent | Mode of Action | Release Sites |
|---|---|---|
| *Galerucella calmariensis* (beetle) | Larvae and adults feed on foliage and flowers | MB, ON |
| *Galerucella pusilla* (beetle) | Larvae and adults feed on foliage and flowers [18] | MB, ON, WA [29,32,97] |
| *Hylobius transversovittatus* (weevil) | Larvae and adults feed on roots [17] | WA [97] |
| *Nanophyes marmoratus* (weevil) | Larvae feed on flowers and adults feed on foliage and flowers [21] | MB [50] |

*Galerucella* beetles have been the most effective biocontrol agents used against purple loosestrife in North America thus far [29,63,97]. *G. calmariensis* and *G. pusilla* are similar in appearance and habit and are most effective when released together, and both species appear to be unaffected by exposure to the herbicides glyphosate and triclopyr [76,77]. Because of "dramatic" success at some *Galerucella* release sites, release of other agents should focus on sites where *Galerucella* have been ineffective. In Europe, *H. transversovittatus* herbivory on purple loosestrife is strongest in the northern range of the plant, indicating that higher latitude sites may be a good choice for its release in North America [51].

*Myzus lythri*, a European aphid that has probably been present in the Eastern United States since the early 1930's, might become an effective biological control agent. It has a host-alternating life cycle, utilizing loosestrife and *Epilobium* spp. in summer and *Prunus* spp. as primary hosts the rest of the year. Populations of *M. lythri* could be manipulated to impact local purple loosestrife populations by mass-rearing bugs for targeted early-spring release and/or by planting *Prunus* spp. near targeted sites [134].

Research examining the potential use of pathogenic fungi as biocontrol agents is ongoing [92].

Chemical: A variety of herbicides are effective at controlling purple loosestrife in infested areas. Below is a list of herbicides that have been used effectively against purple loosestrife in North America, as well as a brief discussion of important considerations regarding their use. This is not intended as an exhaustive review of chemical control methods. For more detailed information regarding appropriate use of herbicides in natural areas against this and other invasive plant species, see The Nature Conservancy's Weed Control Methods Handbook, as well as TNC's Wildland Invasive Species Program web page.

| Chemical | Considerations |
|---|---|
| 2,4-D [13,91,118,140] | Mixed results against purple loosestrife; harmful to dicots, but little impact on neighboring monocots |
| Triclopyr [12,39,62,90,118] | Generally effective at killing purple loosestrife; results are variable with spray volume; selective against dicots |
| Glyphosate [12,81,102,104,118,122,131] | Highly effective against purple loosestrife; specific formulations available for use in aquatic environments; also damages or kills most other plants which it contacts |
| Imazapyr [11] | Effective against purple loosestrife; negatively impacts cattail |

A serious challenge to controlling purple loosestrife infestations with herbicides is preventing its re-establishment from the seed bank. In the presence of large purple loosestrife seed banks, removal of a considerable fraction of extant vegetation (weed or otherwise) can result in a dense monoculture of purple loosestrife seedlings. The result may be a worse infestation than was originally present [91]. Broadcast application of broad-spectrum herbicides, such as glyphosate, will likely result in widespread exposure of bare substrate and a dense, monotypic stand of purple loosestrife seedlings [118]. By carefully targeting glyphosate spray application to only purple loosestrife, damage to nontarget plants can be minimized. Continued careful treatments over several years can eventually reduce dense populations of purple loosestrife to minimal levels while promoting native plants [104,122]. Native plants are not just inherently valued, but can also provide competition against inevitable purple loosestrife recruitment from existing seed banks [118].

An apparent tradeoff exists when determining the best time to treat adult stands with herbicides. Managers must attempt to balance preventing seed production in established plants with treatments early in the growing season and preventing establishment of a viable new stand of purple loosestrife seedlings by delaying treatments long enough to inhibit recruitment. By conducting herbicide treatments on adult plants late in the growing season, newly established seedlings may not develop sufficiently to survive winter [90]. Late-summer herbicide application also appears to reduce negative effects on desirable native plants [81]. Rawinski [102] found that glyphosate application during late-bloom (mid-August in central New York) period, compared with late-vegetative (mid-June) period, resulted in fewer loosestrife seedlings the following season and increased presence of naturally established, beneficial plants such as shallow sedge (*Carex lurida*), rice cutgrass (*Leersia oryzoides*), smartweed and marsh seedbox (*Ludwigia palustris*). Late-season application of glyphosate in Minnesota wetlands tended to reduce cattail mortality compared with mid-summer treatments, perhaps because the onset of cattail senescence reduced herbicide uptake [12].

Another tradeoff exists between spray volume and target vs. nontarget effects. Purple loosestrife in Wisconsin was examined for response to variation in spray coverage of glyphosate (Rodeo at 1.5%). Individual genets were spot treated in mid-September and received either low (10-25% leaf area coverage), medium (40-60%), or high (75-90%) dosages. Reduction in adult purple loosestrife density was greatest in the high dosage treatment (90-100% reduction) and lowest in the low dosage treatment (75-90% reduction). Surviving purple loosestrife plants in all treatments were greatly reduced in size and vigor. Because glyphosate is nonselective in its effect, survival of nontarget vegetation was also closely related to dosage. High dosage treatment resulted in dense stands of purple loosestrife seedlings with little to no interspecific competition. In contrast, low dosage treatment resulted in high survival rates of desirable perennials and greatly reduced germination of purple loosestrife seedlings. Effective long-term control of purple loosestrife with glyphosate might best be achieved using low-dosage spot applications and conducting followup treatments in subsequent years as necessary [104].

To minimize non-target effects, managers in Michigan have developed a cut-and-herbicide method for purple loosestrife control. They propose cutting plants high on the stem (just below infloresence), allowing them to continue growing and better absorb the applied herbicide throughout the entire plant. Cutting too low apparently risks forcing the plant to "give up" on the leader and instead producing new ramets from the rootstock. Sponge applicators have been developed that limit contact between chemicals and nontarget plants [131]. These methods may be particularly useful in areas where mitigation of damage to indigenous species is important. Encouraging competition from extant native plants often helps reduce the vigor of invasives. For more detailed information regarding these methods, visit the TNC Wildland Invasive Species Program website: http://tncweeds.ucdavis.edu/esadocs/lythsali.html." http://www.fs.fed.us/database/feis/plants/forb/lytsal/all.html (Accessed 19 March 2003)

**Agencies Collecting Data:**
Texas Nature Conservancy Wildland Species Program
USDA Forest Service
The Western Aquatic Plant Management Society
Invasive Species Focus Team Gulf of Mexico Program

**References (includes journals, agency/university reports, and internet links):**


1. APMS - http://www.apms.org/plants/loosestrife.htm (Accessed 19 March 2003)
2. FEIS - http://www.fs.fed.us/database/feis/plants/forb/lytsal/all.html (Accessed 19 March 2003)
3. ISSG - http://www.issg.org/database/species/ecology.asp?si=93&fr=1&sts= (Accessed 19 March 2003)
4. Thompson - Thompson, D. Q., Stuckey, R. L. and Thompson, E. B. 1987. Spread, Impact, and Control of Purple Loosestrife (Lythrum salicaria) in North American Wetlands. USGS, Northern Prairie Wildlife Research Center.
5. STPL - http://www.wes.army.mil/el/pmis/plants/html/lythrum_.html
6. ARS - http://www.nal.usda.gov/ttic/tektran/news/purpleloosestrife.htm
7. NAPIS - http://www.ceris.purdue.edu/napis/pests/pls/index.html#maps
8. USGSc - http://usgssrv1.usgs.nau.edu/swepic/asp/swemp/data.asp?Symbol=LYSA2
9. TNC - http://tncweeds.ucdavis.edu/esadocs/lythsali.html
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Virginia Department of Conservation and Natural Resources. 1995. Invasive Alien Plant Species of Virginia: Purple Loosestrife (*Lythrum salicaria*).


**Available Mapping Information:**

PLANTS http://plants.usda.gov/cgi_bin/plant_profile.cgi?symbol=LYSA2 (Accessed March 19, 2003)
STPL - http://www.wes.army.mil/el/pmis/plants/html/lythrum_.html
NAPIS - http://www.ceris.purdue.edu/napis/pests/pls/imap/plsall.html

Notes: For more references refer to the WAPMS Web link.